INTRAOPERATIVE RECORDING OF ENG FROM HUMAN SACRAL NERVE ROOTS

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Abstract-**Intraoperative recoding of ENG from the S3 extradural sacral nerve roots was performed in 2 SCI patients. The goal of this work was to study the relation between mechanical stimulation of the urinary bladder, rectum and skin and the resulting ENG-signals. These signals could be used to detect the onset of a bladder contraction. This concept could be used in an implantable neuroprostheses to treat detrusor hyperreflexia. The recorded human signals are consistent with data from animal studies. However, more human studies are needed.**

Keywords **- Sacral nerve roots, urinary bladder, detrusor hyperreflexia, electrical stimulation, ENG.**

I. INTRODUCTION

Detrusor hyperreflexia (DH) is the most common form of detrusor dysfunction in spinal cord injury and causes a failure of the storage function of the lower urinary tract. It is characterized by involuntary detrusor contractions during bladder filling at relative small volumes which cannot be suppressed consciously and cause an increase in intravesical pressure of more than 15 cm H_2O. DH causes a low storage capacity and transient high intravesical pressures resulting in incontinence, risk for kidney damage and bladder hypertrophy.

The first step in the treatment of DH is medication. However, pharmacological inhibition of DH (e.g. by oxybutynin) is often unsuccessful and its usefulness is limited by intolerance to oral administration due to side effects as salivary reduction with dry mouth, vision disturbance and inhibition of gut motility [1]. Especially in patients with SCI these side effects are very troublesome. In the case of failure of the drug, destructive treatments are advocated such as surgical augmentation of the bladder [2] and surgical deafferentation of the bladder [3].

An alternative option is the use of electrical stimulation. The ratio of this treatment modality is based on the existence of spinal inhibitory systems which are capable of interrupting a detrusor contraction. These inhibitory systems can be activated by electrical stimulation of appropriate afferent nerve fibers. Electrical stimulation would therefore be a non-destructive alternative for patients who are refractory to drugs or cannot tolerate the side effects.

Bladder inhibition can be achieved by stimulation of afferent anorectal branches of the pelvic nerve, the dorsal penile/clitoris nerve [4], the pudendal nerve and the dorsal sacral nerve roots [5]. Several studies have shown that electrical stimulation of these afferents may have long lasting effects on bladder inhibition in non-neuropathic bladder dysfunction. However, this is not the case in neuropathic bladder dysfunction [6]. So chronic stimulation is needed.

The stimulator could be on continuously during the filling phase although stimulation is actually only needed to inhibit a contraction. The stimulator could thus be turned off if no reflex contractions are present. In order to allow event driven stimulation a sensor is needed that detects the onset of a contraction.

Implantable sensors with sufficiently long biocompatibility and reliability are difficult to build, but with the advent of methods for long-term electrical interfacing with nerves, recording from natural sensors in the body have become a realistic alternative [7]. The goal in this ongoing project is to monitor mechanical bladder activity by recording nerve signals from nerves innervating the urinary bladder. Previous work in acute pig experiments [8] has shown that cuff electrodes placed on S2/3 sacral roots could be used to record ENG originating from bladder, rectum and cutaneous receptors. Subsequent chronic implants in pigs showed that these signals can also be reliably recorded with implanted electrodes. In this abstract we report on measurements from sacral nerve roots in 2 SCI patients performed at the Guttmann Institute in Barcelona, Spain.

II. METHODOLOGY

The local ethical committee of the Guttmann Institute approved the protocol and both patients signed an informed consent. Measurements were obtained from 2 female patients with a complete spinal cord injury (Patient 1: T3, age: 44 years, 3 years post injury; Patient 2: T8, age 40, 18 years post injury).

1) *Patient preparation:* The patients underwent implantation of an extradural Finetech-Brindley sacral ventral root stimulator [9]. During the operation, access to the extradural sacral nerve roots was gained after a laminectomy. Individual nerve roots were identified by their size and by the response of several muscle groups to electrical stimulation with a hook electrode. After identification a tripolar cuff electrode, to be used for recording, was placed around a complete extradural S3 sacral nerve root (right side). Saline at body temperature was poured on the nerves to prevent them from drying. The cuff electrode was completely submerged during the experiment. At this point the leads were connected to an aseptic amplifier/telemeter [12] and for 15-20 minutes ENG was recorded while the skin, rectum and bladder were mechanically stimulated. After these measurements the cuff electrode was removed and the surgical procedure resumed with a complete extradural dorsal rhizotomy and implantation of the extradural stimulation electrodes.

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2) *Recording:* The patients were instrumented with a single lumen transurethral catheter to perform bladder filling and to measure intravesical pressure. Two catheters were inserted in the rectum, one for rectal distention, and one to measure rectal pressure. In addition two surface electrodes were placed next to the clitoris for stimulation of the dorsal clitoral nerve.

The cuff electrodes were made of (medical grade) silicone with 3 circular biocompatible platinum foil contacts. Similar electrodes have been used in chronic human applications to control handgrasp and to restore dropfoot [10,11].

The cuff electrode was connected to a battery powered amplifier/telemeter [12]. The amplified signals were sent to an external receiver, sampled at 20 KHz and stored with the bladder and rectal pressures on a digital audio recorder. The ENG-signals were also made audible through a loudspeaker.

The following experimental protocol was used:

- ENG was recorded while the relevant sacral dermatome was tapped by a gloved hand.
- ENG was recorded during consecutive rapid injections of 50 ml warm saline into the bladder to study the relation between mechanical bladder activity and the ENG signals.
- ENG was recorded during consecutive rapid injections of 50 ml warm saline into the rectum to study the relation between mechanical rectal activity and the ENG signals.
- The clitoral nerve was stimulated (10 Hz, 10-35 mA) using surface electrodes at different amplitudes using a handheld stimulator. The resulting evoked compound action potentials were picked up with the cuff electrode.

III. Results

A. Cuff electrode

Patient 1 received a tripolar cuff electrode of 12 mm length (contact spacing: 5 mm; contact width: 1 mm). The cuff had an inner diameter of 3 mm. This cuff snuggly fitted around the nerve. Patient 2 received a similar cuff electrode but with an inner diameter of 2.6 mm as the nerve bundle was slightly smaller.

B. Patient 1

No ENG could be recorded in response to stimulation of the dermatomes, bladder distension or rectal distention. Only a weak response was present during stimulation of the dorsal clitoral nerve.

C. Patient 2

The ENG recorded during touching of the dermatomes (mainly buttocks) was very clear on the loudspeaker. Fig.1 shows both the raw signal and the bandpassed (200 Hz-4 kHz) rectified and bin integrated signal (Tbin=50 ms). The presence of ENG cannot directly be seen in the raw signal but becomes clear after processing. The first and last few seconds in fig.1 show the background noise (around 0.6 μV). The bust of activity in the between is the response to skin manipulation. The maximum amplitude of these cutaneous signals is about 0.8 μV.

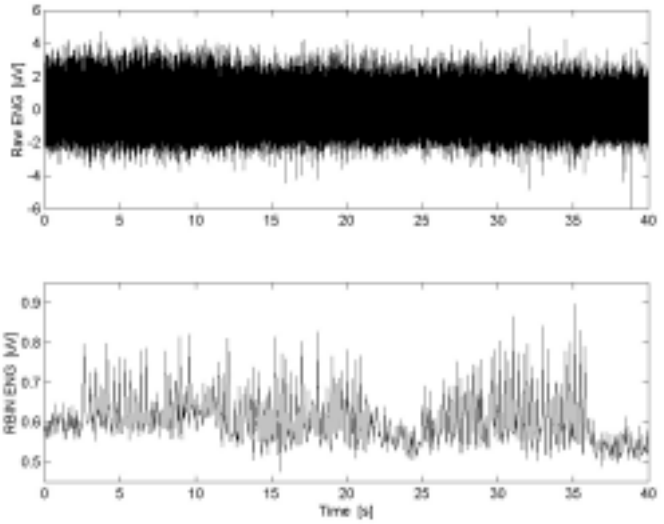

Fig. 1. Raw (top) and processed (bottom) ENG during skin tapping.

Fig. 2 shows the recorded ENG (rectified, bin integrated and low pass filtered at 2 Hz) during bladder distension. Five consecutive injections of 50 ml each were carried out at around 20, 70, 110, 150 and 200 s respectively. These injections are visible as an increase in bladder pressure in fig. 2 (middle trace). Rectal pressure does only change little during bladder filling.

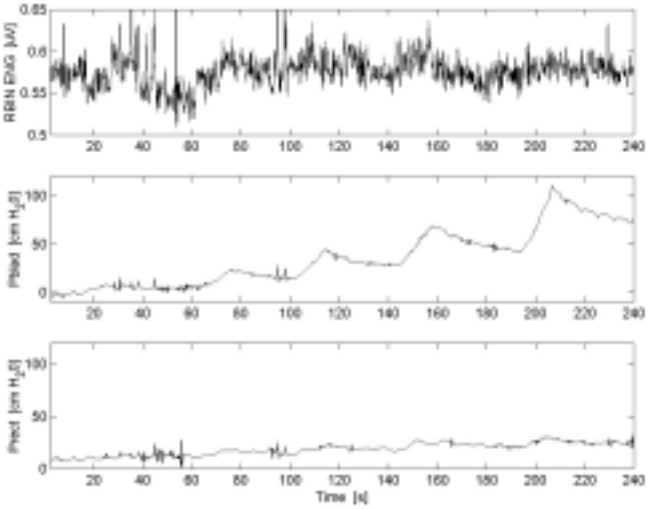

Fig. 2. Rectified, bin integrated and low pas filtered ENG (top), bladder pressure (middle), rectal pressure (bottom) during 5 consecutive injections of 50 ml into the bladder.

Small phasic increases are present in the ENG-response during the first, second and fourth injection but they were absent during the third and fifth injection.

Fig. 3 shows the recorded ENG (rectified, bin integrated and low pass filtered at 2 Hz) during rectal distension. Four consecutive injections of 50 ml each were carried out at around 10, 30, 55 and 70 s, respectively. These injections are visible as a rapid increase in rectal pressure in fig. 2 (bottom trace). Bladder pressure does not change much during rectal distention. It only decreases gradually as bladder is drained after the filling experiment.

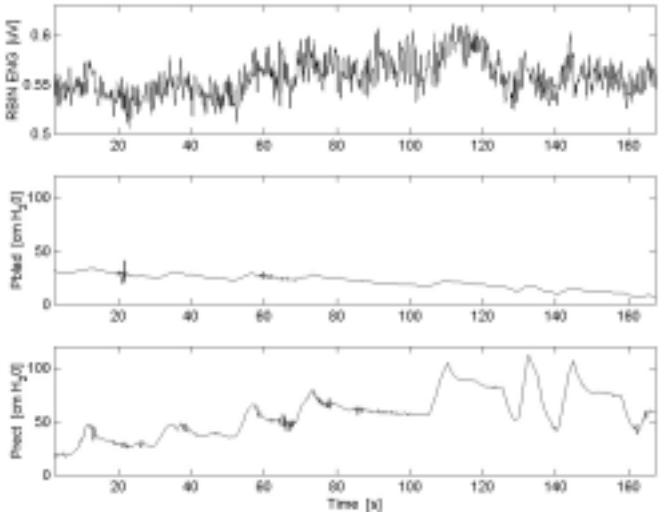

Fig. 2. Rectified, bin integrated and low pas filtered ENG (top), bladder pressure (middle), rectal pressure (bottom) during 4 consecutive injections of 50 ml into the rectum.

After the fourth injection 50 ml has been taken out and injected again. This has been repeated a few times and is visible as large rectal pressure changes after 100 s.

Recordings of compound action potentials (CAP) induced by clitoral nerve stimulation using a bipolar surface electrode were reproducible but the amplitude of the CAPs were rather low (3.2 μV). The distance from the stimulation electrode to the recording cuff electrode was estimated to be 0.25 m suggesting a propagation velocity of 50 m/s.

IV. Discussion

In the first experiment no data was recorded which correlated to manipulation of bladder and rectum. Also ENG related to skin tapping was absent. Inspection of the cuff electrode after the experiment revealed that electrode contacts were bend and partially detached from the inside of the cuff. As this may have happened during the placing of the electrode it explains why no signals were recorded.

In the second experiment the recorded signals were distinct nerve signals with a relative small amplitude. The small amplitude may be explained by the rather large inner diameter of the cuff electrode. With a smaller diameter cuff electrode, larger signal amplitudes are expected. However, the minimum cuff diameter is limited by the diameter of the nerve bundle. Alternatively the cuff electrode could be placed intradurally. At this location the roots are not surrounded by a perineurium sheath one could separate the dorsal and ventral roots. A smaller cuff could then be used to record from only the dorsal roots.

V. Conclusion

Intraoperative ENG recordings from human sacral roots have been performed. The recordings are in accordance with results from similar experiments performed in pigs [8]. However more human experiments are needed to elucidate whether this way of monitoring bladder activity could be used to detect the onset of a bladder contraction.

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